MECHANICAL POWER IN THE INDUSTRIALIZATION OF JAPAN: A CASE STUDY OF THE SPINNING INDUSTRY

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As was explored in the previous paper, "Mechanical Power in the Industrialization of Japan," the rapid industrialization in pre-World War Japan was accompanied with a rapid change in mechaniclal power.[1] The growth rate of manufacturing output was high compared with those for other developed countries. On the other hand, the total horsepower capacity of this industry showed such a high rate of growth as 13% per year for 1891–1937, higher than the rate of growth in real output. Furthermore both the transition from human power to mechanical power and the transition of mechanical power by type, from water wheels to steam engines and from steam engines to electric motors, went on at a higher speed than that for other developed countries. These changes in power source, which may be referred to as "power revolution," should have made great contributions to the industrialization. In the aforementioned paper I argued on these contributions by taking examples of some industries including spinning and printing industries. However the full-scale arguments for individual industries have been retained to another papers. A mimeographed paper has been prepared for summarizing a study on printing and this present paper aims a detailed study on the spinning industry.[2]

The spinning industry, which began to develop somewhat later than the silk-reeling industry, was one of Japan's major industries prior to World War II. Output of yarns increased rapidly after the 1880s and exceeded output of raw silk some time in the 1910s. This increase made possible import substitution and later stimulated export expansion.

This chapter concerns the spinning industry as a whole, but historical examples mainly refer to cotton spinning. Among the various spinning industries cotton spinning was by far the most important. In 1909, for example, there were 111 factories producing cotton yarn, compared with 19 producing hemp yarn, 9 producing silk yarn, and 4 producing woolen yarn.[3] Furthermore, the value of both output and export of cotton yarn was larger than that of all other types of yarn combined.[4] Thus, given the predominant position of cotton spinning, the impact of the power revolution in the spinning industry in general can be largely understood from our examination of its impact on cotton spinning alone.

The first section surveys the statistical dimensions of the power revolution in spinning and the second section explores its impact on the production of yarn.

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[1] Minami 1977. Also see Minami 1976a; 1976b.

[2] Minami 1978.

[3] Nōshōmushō, *Kōjō Tōkei Hyō* 1909.

[4] See the above footnote.

I. *Quantitative Survey of Power Utilization*

Mechanization

By the first decade of the twentieth century the spinning industry was already rather highly mechanized. As shown in Table 1, the proportion of powered factories (with 10 or more workers) in the spinning industry exceeded 80% in 1900. This proportion is more than double that in manufacturing as a whole (32.3%) and quite a bit larger than the proportion in silk reeling (49.6%) in the same year. By 1909 the proportion had surpassed 90% in spinning plants with 5 or more workers, while it was less than 30% in manufacturing plants as a whole and only about 67% in silk-reeling plants. These comparisons clearly indicate that the spinning industry was a leader in mechanization during the early years of industrialization. Furthermore, by the beginning of the twentieth century the degree of mechanization in spinning far exceeded even that in silk reeling. This was the case even though silk reeling began to mechanize earlier than spinning and most other industries.

TABLE 1. PROPORTION OF POWERED FACTORIES AND COMPOSITION OF TOTAL POWER CAPACITY BY ENGINE TYPE IN SPINNING: 1885–1915

(percent)

Year	Proportion of Powered Factories	Composition of Power Capacity			
		Electric Motors	Steam Engines and Turbines	Internal Combustion Engines	Water Wheels and Turbines
1885			69.9		30.1
1890			96.8		3.2
1895			94.5		5.5
1900	83.2	1.1	88.0	0.0	10.9
1905	82.4	1.7	87.4	0.1	10.8
1910	81.9	13.9	71.2	7.0	7.9
1915	98.6	25.6	71.2	1.1	2.1

Source: Nōshōmushō, *Nōshōmu Tōkei Hyō* 1885–1915.
Note: Private factories with ten or more production workers. In 1885, 1890 and 1895 electric motors and internal combustion engines were not included in this survey. But they were negligible.

The higher degree of mechanization in the spinning industry in the earlier years resulted largely from the fact that mechanization was relatively advanced in small-scale spinning plants. This fact is revealed in Table 2, which shows large figures of the proportion in these plants. In 1909 for example, the proportion was 68.4% in the smallest scalecate gory (5–9 workers) and 85.7% in the second smallest scale category (10–29 workers). Comparable figures for manufacturing as a whole were 14.4% and 30.1%. Moreover, in the same year all spinning plants employing 30 workers or more were mechanized. In the manufacturing sector as a whole, on the other hand, the proportion ranged from 63.7% to 100% in large-scale plants.

TABLE 2. PROPORTION OF POWERED FACTORIES BY FACTORY SCALE IN SPINNING

(percent)

Scale (person)	1909	1914	1919	1930	1935	1940
All factories	93.7	96.2	96.5	98.5	99.5	99.8
5 — 9	68.4	100.0	90.6	95.5	99.1	99.8
10 — 29	85.7	83.3	98.6	97.7	98.4	99.3
30 — 49	100.0	25.0[a]	100.0	100.0	100.0	100.0
50 — 99	100.0	100.0	100.0	100.0	100.0	100.0
100 — 499	100.0	100.0	100.0	100.0	100.0	100.0
500 — 999	100.0	100.0	100.0	100.0	100.0	100.0
1,000 or more	100.0	100.0	100.0	100.0	100.0	100.0

Source: Nōshōmushō, *Kōjō Tōkei Hyō* 1909–1940.
Note: Private factories with five or more production workers.
[a] This abnormality is probably largely due to the very small sample for this scale (only four factories).

TABLE 3. COMPOSITION OF TOTAL POWER CAPACITY BY ENGINE TYPE AND BY FACTORY SCALE IN SPINNING: 1909–1940

(percent)

Scale (persons)	Electric Motors	Steam Engines and Turbines	Internal Combustion Engines	Water Wheels and Turbines	Electric Motors	Steam Engines and Turbines	Internal Combustion Engines	Water Wheels and Turbines
		1909				1930		
All factories	7.3	86.1	1.1	5.5	87.2	12.4	0.3	0.1
5 — 9	0.0	0.0	5.4	94.6	61.2	7.8	0.0	31.0
10 — 29	16.3	4.6	11.8	67.3	77.9	13.7	0.0	8.4
30 — 49	0.0	78.0	0.0	22.0	90.7	4.4	0.0	4.9
50 — 99	0.0	84.2	0.0	15.8	45.5	54.5	0.0	0.0
100 — 499	3.7	74.0	0.1	22.2	95.0	4.5	0.3	0.2
500 — 999	0.5	93.9	1.9	3.7	97.1	2.7	0.1	0.1
1,000 or more	10.0	85.7	1.1	3.2	74.9	24.7	0.4	0.0
		1914				1935		
All factories	18.8	75.6	2.1	3.5	84.6	13.7	1.5	0.2
5 — 9	8.3	19.4	11.1	61.2	66.7	0.0	0.0	33.3
10 — 29	32.7	0.0	45.5	21.8	90.3	0.0	1.8	7.9
30 — 49	0.0	0.0	0.0	100.0[a]	89.2	2.2	0.0	8.6
50 — 99	42.3	0.0	0.0	57.7	86.9	13.1	0.0	0.0
100 — 499	22.7	42.4	2.0	32.9	93.0	3.0	3.3	0.7
500 — 999	6.2	91.5	2.3	0.0	93.7	3.1	3.0	0.2
1,000 or more	21.7	76.1	1.9	0.3	79.3	20.1	0.6	0.0
		1919				1940		
All factories	54.2	43.1	0.9	1.8	92.8	6.9	0.2	0.1
5 — 9	21.9	0.0	38.0	40.1	69.0	0.0	1.2	29.8
10 — 29	44.0	3.3	20.1	32.6	93.2	0.0	0.0	6.8
30 — 49	58.1	13.9	11.8	16.2	98.6	0.0	0.0	1.4
50 — 99	78.8	0.0	8.6	12.6	99.9	0.1	0.0	0.0
100 — 499	46.1	28.6	3.2	22.1	96.3	3.0	0.5	0.2
500 — 999	37.8	60.3	0.7	1.2	97.8	1.9	0.3	0.0
1,000 or more	56.8	42.0	0.6	0.6	86.2	13.8	0.0	0.0

Source: Same as Table 2.
Note: Private factories with five or more production workers.
[a] See the footnote to Table 2.

Transition of Power Capacity by Engine Type

In 1884 water wheels were still the largest source of mechanical power in the spinning industry, comprising 62.8% of total power capacity. But in the next year, due to rapid growth in the use of steam engines, steam power exceeded water power (Table 1). The share of steam power in total spinning power capacity peaked around 1890. The decline thereafter occurred because of the spreading application of electric motors. The share of electric power surpassed that of steam power between 1914 and 1919 (Table 3). By 1940 the share of steam had fallen to only 6.9%, compared with steam's 16.4% share of total power capacity in the manufacturing as a whole. Thus, one aspect of the power revolution, the replacement of steam by electricity, occurred particularly rapidly and intensely in the spinning industry.

There did, however, exist a clear difference in power utilization between spinning plants with less than 30 workers and plants of larger sizes.[5] As shown in Tables 3 and 4, in 1909 steam power was rarely used and water power was dominant in the smaller scale plants, whereas steam was the primary source of power among large-scale plants. Among small-scale spinners the use of steam power decreased over the next decade, and by 1919 electric motors and internal combustion engines were widely used. Then, during the 1920s internal combustion engines were almost completely replaced by electric motors in these small plants. Large-scale spinning plants, on the other hand, rarely used internal combustion engines. Instead, these plants moved rather steadily to replace steam engines by electric motors. This substitution was largely complete by 1930.

II. *The Power Revolution and Technological Progress*

The Impact of Water Wheels and Steam Engines

Traditional sector. The spinning industry in Japan eventually developed along two lines. A large segment of the industry adopted modern western production methods, but there remained a significant number of spinners who retained traditional domestic technology. Even in this traditional sector, however, the power revolution, particularly the introduction of water wheels, had a great impact on spinning technology and on yarn production.

During the early Meiji period cotton yarn was produced with the *gara*-spinning (cup-throstle spinning) technique. This method was invented in 1876 by Tatsuchi Gaun, a priest in Minami Azumi District of Nagano Prefecture, and was awarded the highest prize at the *Dai-1-Kai Naikaku Kangyō Hakurankai* (First industrial exhibition) held the following year.[6] The *gara* spinner, basically an improvement on the hand-spinning technique inherited from the Tokugawa period, used tubes made of tin plate, one inch in diameter

[5] The number of factories with 5–29 workers increased rapidly from 40 in 1909 to 584 in 1940. Larger factories increased from 103 to 375 in the same period. *Kōjō Tōkei Hyō* 1909, 1940.

[6] The readings of the characters for Gaun's given name offer several possible pronounciations (eg. Tatsuchi, Tokimune, Tatsumune, Shinchi), but it is now believed that Tatsuchi is the correct one.

For the history of *gara*-spinning technology, we referred to Gendai Nippon Sangyō Hattatsushi Kenkyūkai 1964b; 1967; Nippon Sen-i Kyōgikai 1958b.

and 5 to 7 inches long. Row cotton was stuffed into revolving tubes. Twisted thread was formed by pulling the cotton through the tubes and winding it over bobbins.

The introduction of this technique raised labor productivity considerably. Daily output of a female worker, which had averaged 40–50 *monme* with the old spinner, increased to 650 *monme* with the *gara* spinner.[7] The rapid diffusion of the new spinner throughout the country was due both to its greater efficiency and its low equipment cost.

As the *gara* technique spread, water-powered versions of this equipment were developed. One document records that by introducing water wheels the number of spindles operated by one worker increased from 30 to 100.[8] The pairing of the water wheel and the gara

TABLE 4. COMPOSITION OF PRIMARY POWER CAPACITY BY ENGINE TYPE AND BY FACTORY SCALE IN SPINNING: 1909–1919

(percent)

Scale (persons)	Primary Electric Motors	Steam Engines and Turbines	Internal Combustion Engines	Water Wheels and Turbines
		1909		
All factories	0.2	92.7	1.2	5.9
5 — 9	0.0	0.0	9.1	90.9
10 — 29	16.3	4.6	11.8	67.3
30 — 49	0.0	78.0	0.0	22.0
50 — 99	0.0	84.2	0.0	15.8
100 — 499	1.8	75.5	0.1	22.6
500 — 999	0.0	94.4	1.9	3.7
1,000 or more	0.0	95.2	1.2	3.6
		1914		
All factories	11.5	82.5	2.2	3.8
5 — 9	8.3	19.5	11.1	61.1
10 — 29	32.7	0.0	45.5	21.8
30 — 49	0.0	0.0	0.0	100.0[a]
50 — 99	42.3	0.0	0.0	57.7
100 — 499	21.5	42.9	2.1	33.5
500 — 999	3.1	94.5	2.4	0.0
1,000 or more	12.4	85.1	2.1	0.4
		1919		
All factories	33.5	62.7	1.2	2.6
5 — 9	20.4	0.0	38.7	40.9
10 — 29	44.0	3.3	20.1	32.6
30 — 49	56.7	14.3	12.2	16.8
50 — 99	78.8	0.0	8.6	12.6
100 — 499	31.0	36.6	4.1	28.3
500 — 999	33.2	64.7	0.8	1.3
1,000 or more	33.5	64.6	0.9	1.0

Source: Same as Table 2.
Note: Private factories with five or more production workers.
[a] See the footnote to Table 2.

[7] Uchida 1960, p. 146.

[8] Kanbayashi 1948, p. 64. Uchida cites the fact that by introducing water power daily output per worker increased to 18 *kan* of fine thread and 7 *kan* of thick thread, but he does not give earlier output figures for comparison (1960, p. 146).

TABLE 5. NUMBER OF SPINNING BOATS AT NAKAHATA IN MIKAWA

Year	Number of Boats
1879	3
1882	46
1898	59
1905	40
1917	27
1922	17
1926	13
1933	7
1934	0

Source: Nippon Sen-i Kyōgikai 1958b, Table 1 of chap. 6 on p. 381.

spinner was responsible both for the high percentage of powered factories among small-scale spinners in the early years and for the heavy reliance of these plants on water power. In addition, water-powered *gara* spinning became popular as a source of supplemental income for farmers. The spread of water-powered *gara* spinning made possible in large part the growth of domestic output of cotton yarn through the 1880s.

The water-powered *gara* spinner became the mainstay of the traditional spinning industry. The continued viability of this traditional sector was due largely to advances in the application of water power. To see the impact of water power on this technique we will take as an example the Mikawa region of Aichi Prefecture, where *gara*-spinning technique made the greatest progress. Here water wheels were utilized in two ways. One method was called *funa bōseki* (boat spinning) or *mizu no garabō* (*gara* spinning on the water) and the other was known as *suisha bōseki* (water wheel spinning) or *yama no garabō* (*gara* spinning in the mountains).

The first method, *funa bōseki,* was introduced in 1878 by Rokusaburo Suzuki. In that year Suzuki learned of the high reputation which the *gara* spinner had earned at the industrial exhibition and visited Gaun to purchase some machines. Together, he and Gaun carried the spinners to Yokosuka Village in the Hazu District of Mikawa. After an unsuccessful attempt to operate the machines with a stationary water wheel, they installed the spinners in a boat floating on the Yahagi River and powered them with a water wheel set in the boat. As is shown in Table 5, the number of such spinning boats increased from only 3 in 1879 to 46 in 1882. Family members and employees of the owner often lived together on these boats. Boat spinning benefitted from several subsequent innovations. Around the year 1885 spinners with 30 to 90 spindles were driven by water wheels placed on one side of each boat, and around 1907 two water wheels, one on each side of every boat, turned machines with 240 to 320 spindles. The number of spinning boats began decreasing after reaching a peak in 1898. As boat spinning became less profitable than electric powered spinning, boat operators gradually switched to land-based factories. Finally in 1934 the last spinning boats disappeared, having been displaced because of river conservation.

The second spinning method, *suisha bōseki* or water wheel spinning, also developed in Mikawa. Its use there dates back to 1879. In that year Takisaburo Komura installed a *gara* spinner with 60 spindles in a communally owned water mill in Takaoka Village in the Aomi District. Later Komura moved to Tokiwa Village in the Nukata District and continued his experiment with water-powered spinners. His technique was quickly adopted in this village and in others in the Nukata District, a region with abundant streams. A number of water wheels which had previously been used only for processing rice and grinding rape seeds were converted to spinning. The number of spindles in establishments belonging to the *Mikawa Garabō-Ito Kōgyō Kumiai* (Mikawa Gara-Spinning Manufacturing Association) tripled in the short span from 1884 to 1887 (Table 6). The association's output quintupled over the same period.

According to Table 6, the number of spindles and output at the Mikawa establishments fell dramatically between 1887 and 1892. This setback in *gara* spinning was the result of the development of the modern cotton-spinning sector and of increased textile imports. *Gara* spinning could not compete with modern technology either inside or outside of Japan.

Table 6 also shows, however, that after 1892 water-powered *gara* spinning experienced a recovery. Both output and the number of spindles increased regularly over the twentieth century right up to World War II.[9] This was due to the fact that, in order to survive in the face of competition from modern technology, these traditional spinners specialized in producing low-quality, thick cotton yarns which were used in weaving carpets, blankets, flannel, soles for *tabi* (Japanese socks), and so forth. Furthermore, these spinners began to use rags, cotton discarded by the modern spinning plants, and other waste thread in order to save on production costs.

Modern sector. Modern cotton-spinning techniques were introduced in the 1860s by the Satsuma Clan, which imported spinning machines from England.[10] In 1867 this clan established Japan's first steam-powered factory, the Kagoshima Spinning Mill, and in 1870 erected a second steam-powered mill, the Sakai Spinning Mill. Although these two

TABLE 6. NUMBER OF SPINDLES AND QUANTITY OF OUTPUT OF THE MIKAWA GARA-SPINNING MANUFACTURING ASSOCIATION: 1884–1937

	Number of Spindles	Quantity of Output
	(1,000)	(1,000 *kan*)
1884	44	62
1887	132	309
1892	75	187
1897	115	435
1902	123	666
1907	158	901
1912	173	1,236
1917	210	1,144
1922	365	1,964
1927	351	1,371
1932	399	1,956
1937	748	3,489

Source: Nippon Sen-i Kyōgikai 1958b, Table 3 of chap. 6 on p. 382.

[9] This fact seems to explain the aforementioned increase in the number of small spinning plants between 1909 and 1940. See n. 5.

[10] For the history of the modern cotton-spinning industry before World War II, we referred to Gendai Nippon Sangyō Hattatsushi Kenkyūkai 1964b; 1967; Kiyokawa 1973; Nippon Sen-i Kyōgikai 1958b.

earliest modern spinning mills both employed steam engines, almost all other modern spinning plants established in the next few years were equipped with water wheels. Despite the initial simultaneous appearance of modern spinning technology and steam-powered spinning, water power was the main route by which the modern technology was introduced in Japan. The Kashima Spinning Mill, established in 1872, was powered by a 25-hp water wheel run by water supplied from the Senkawa Aquaduct, a branch of the Tamagawa Acquaduct.[11] In addition, those spinning mills which were erected between 1881 and 1885 either directly by the government or with the financial help of the government under the *Shokusan Kōgyō Seisaku* (Policy to promote industrialization) were largely dependent on water power.[12] For example, the government-operated Aichi and Hiroshima Spinning Mills were powered by water wheels. And, among the fifteen privately owned mills established under this industrialization policy, eight were equipped with water wheels and one installed both a water wheel and a steam engine. In conjunction with this policy, the Meiji government encouraged use of water power in place of steam power because of the scarcity and high price of coal.[13] However, these first modern plants were not successful and all shortly shut down.

The Osaka Spinning Mill, established in 1883, was the first commercially viable mill to use modern technology. Its success can be attributed to overcoming several of the problems which afflicted the earlier mills. First, the company trained engineers in advance at mills in England and Japan and so did not suffer from a lack of skilled manpower. Second, the Osaka Mill was much larger than the others and its 10,000 spindles made it possible to reap the advantages of economies of scale. Third, the mill was equipped from the outset with a steam engine. The earlier water-powered mills had suffered because of the inefficiency and unreliability of their production power.[14] Fourth, the Osaka Mill used high-quality imported raw cotton in place of the inferior domestic raw cotton used by the other plants. In addition a double-shift labor force system introduced at Osaka Spinning significantly reduced production costs and contributed to the plant's success as a commercial venture.

The success of Osaka Spinning motivated the fusciculation of other modern, large spinning mills. In 1887 plants with more than 10,000 spindles were built by a number of companies including Tenman Spinning, Tokyo Spinning, Kanegafuchi Spinning, and

[11] The Kagoshima, Sakai, and Kashima spinning mills are known as the *shiso san-bōseki* (three pioneer spinning mills).

[12] These mills, seventeen in total, were all of approximately equivalent size. They are known as the *nisen-sui bōseki* (spinning mills with two-thousand spindles).

[13] There are no records which compare the power costs of water wheels and steam engines in the Japanese spinning industry. However, a study by Peter Temin on cotton-spinning mills in the United States is suggestive. He compared the annual power costs per horsepower in the water-powered mills at Lowell, Massachusetts and the steam powered mills at Newburyport, Massachusetts. He found that power costs were rather higher in the steam-powered mills, because of high operating costs, especially the high cost of coal. Temin 1966, table 4 on p. 197.

[14] Unlike the Kashima Spinning Mill, which was powered by artificial water stream, almost all of the early modern spinning mills suffered from seasonal insufficiency in water because they relied on natural streams. Sueo 1980, p. 178. Consequently three of the *nisen-sui bōseki* which were powered by water wheels installed steam engines as an additional source of power soon after their establishment. In the plan for the Osaka Spinning Mill water wheels were to be used for power. But a survey on water resources in the area revealed that the 140–150 hp of water power, which would be required to run the 10,000 spindle machines was not available. Thus, the original plan was changed and the decision was made to use steam power. Harada 1973, pp. 175, 177.

Hirano Spinning. Over the next few years production of cotton yarn increased considerably and exceeded domestic demand in 1890. By 1896 exports of cotton yarn surpassed imports. The substantial development of the spinning industry, to the point of achieving import substitution and subsequently expanding yarn exports, was made possible by the introduction of steam power in the modern spinning sector.

Electrification

Electric lighting. In spinning mills, as well as in other kinds of factories, electric lighting was introduced much earlier than electric motive power. A pioneer in this field was the Sangenya Plant of Osaka Spinning. In 1886 Tokyo Electric Light Company lit electric lamps in this plant by electricity generated by an American-made 25-kW direct-durrent dynamo.[15] This innovation contributed to the reduction of production costs by extending production time. Although Osaka Spinning had begun operating with a night shift before the introduction of electric lights, there had been a movement for the abolition of night shifts because of the danger of fire from kerosene lamps.[16] Electrification eliminated this danger and permitted the widespread use of the efficient night-shift system.

Introduction of motors. Where in Japan electric motors were first used in spinning is unknown. One document suggests that a mill in Kyoto may have been the first in the spinning industry to employ electricity for motive power.[17] Keage Power Plant began generating electricity for this mill in 1892, but it is not certain whether the electricity was used for driving motors or simply for lighting. According to this same document, however, it is certain that the Suruga Koyama Plant of Fuji Gas Spinning employed electricity for motive power in 1903. The records clearly state that this plant ran a 150-hp direct-current motor from a 120-kW dynamo.

Substantial progress in the electrification of spinning mills was realized with the development of electric utilities which supplied cheap electric power. The Shikanjima Plant of Osaka Spinning was one of the first spinning plants electrified by purchased power. This occurred in 1907.[18] Electrification spread throughout the spinning industry during the 1910s and 1920s. By eliminating the power plant through the use of purchased power, spinning mills saved greatly on capital and operating costs. Thus, purchased electricity proved cheaper than either direct drive or indirect drive by steam power.

It was the shift from group drive to unit drive, however, which gave electrification a decisive advantage. In a group-drive system, power was transmitted by long shafts and a group of belts from one or two engines to individual machines, whereas with unit drive an individual machine was run directly by its own small motor. From the end of World War I until the middle of the 1920s, unit drive was employed with that spinning machinery which required shifts in speed, while group drive was still widely used with other machinery. An increase in the domestic production of small induction motors facilitated the diffusion of the unit-drive system beginning in the 1920s.[19] Between 1930 and 1931 the Inami Plant

[15] Arisawa 1960, p. 39; Gendai Nippon Sangyō Hattatsushi Kenkyūkai 1964a, chronological table.
[16] Arisawa 1959, p. 67.
[17] Meiji Kōgyōshi Hensan Iinkai 1928, pp. 455–56.
[18] Nippon Sen-i Kyōgikai 1958a, p. 788.
[19] These motors, which were of 6–8 hp, were called "ring motors." Tsunekawa 1916, p. 93

of Kureha Spinning and the Sasazu Plant of Tenman Weaving introduced this system to all production stages up to and including the actual spinning operation. Then, in 1932, the Sekigahara Plant of Dai-Nippon Spinning became the first to employ this system for all processes from mixing raw cotton to twisting and reeling.[20]

The advantage of the unit-drive system. The shift from group drive to unit drive was one of the major technological advances in the spinning industry before World War II.[21] The advantages of unit drive were several-fold. First, long shafts and groups of belts no longer restricted the location of machinery within plants. As a result, factory layout could be organized with regard to production efficiency. Second, because floor space could be reduced and because sturdy structures to support the shafts and belts became unnecessary, the unit-drive system led to savings in capital costs. Third, abolishing the drive belts reduced the scattering of cotton dust and improved sanitary conditions for the workers. Fourth, output quality improved because the elimination of shafts and belts kept the running speed of machinery constant.[22] Fifth, with unit drive some machines could stand idle without wasting energy. This advantage was particularly significant to the spinning industry, which was characterized by frequent reductions in operations.[23]

Although it is undeniable that the introduction of the unit-drive system raised productivity and decreased production costs, there are practically no quantitative studies which examine these effects of the unit-drive system. A 1937 study by an engineer Sakio Imamura, which was made public by Fumio Moriya, is one of the rare examples. This study shows that daily output of 40-count cotton yarn increased from 39.25 *monme* to 51.30 *monme* per spindle with the shift from group to unit drive. At the same time electric power consumption increased from 692 kWH to 825 kWH. Moriya, who was skeptical of Imamura's estimates of electric power consumption, presented alternative estimates which show that in production of 20-count yarn, power consumption fell from 283 kWH with group drive to 263 kWH with unit drive.[24] In contrast to Imamura's study, Moriya's figures indicate that the shift to unit drive both raised output per spindle and reduced electric power consumption.

Although unit drive may have reduced operating costs by reducing electric consumption, a third study by Shigetaro Matsumura indicates that the cost of equipment excluding electric power generators (electric wire, motors, shafts, and so forth) was probably greater for the unit-drive than for the group-drive system. Matsumura studied spinning mills which used steam-generated electric power and found that equipment costs ranged between ¥83 and ¥95 per kWH for the unit-drive system while they were only ¥75 for the group-drive system.[25] From these few studies we cannot reach a definite conclusion about the net effect of the introduction of the unit-drive system on total production costs. Nevertheless, the increase in output and production efficiency coupled with the numerous advantages of the elimination of the shafts and belts most certainly made unit-drive production in the spinning industry far superior to the group-drive system.

[20] Moriya 1948, p. 81.
[21] The advantages of unit drive in spinning have been pointed out by many authors: Arisawa 1960, p. 59; Iijima 1949, pp. 201–02; Kajinishi 1948, pp. 90–91; Moriya 1948, pp. 80–81; Nippon Sen-i Kyōgikai 1958a, p. 788; 1958b, pp. 33–34. We have relied heavily on these studies.
[22] Matsumura emphasized this advantage (1923, p. 159).
[23] Kiyokawa 1973, p. 133.
[24] Moriya 1948, p. 80.
[25] Matsumura 1923, p. 154.

III. *Concluding Remarks*

The spinning industry in the earlier years was characterized by a coexistence of the traditional and the modern technologies. The traditional technology, which was employed in the small-scale plants, was powered by the traditional water wheels in these years. The utilization of this power peaked at the turn of the century; later this power was repaced by internal combustion engines and electric motors.

On the other hand, the modern technology was introduced by the large-scale plants in conjunction with steam power. That is, in the Japanese modern spinning industry an age of water power never really existed and therefore the traditional pattern of power revolution, a shift from water to steam, was not obvious. This industry made great contributions to the so-called economic take-off of Japan through import substitution and export expansion in the 1880s and 1890s. In turn this implies that steam power played a decisive role in the economic take-off. This experience differed from that of England, where water power was a dominant source of power in the early stage of industrialization. Since the turn of the century steam power was gradually replaced by electric power. This change was one of the major technological progress in this industry. Especially a shift from group drive to unit drive, which was realized by the electrification, was of a great significance.

In short a study on the spinning industry confirms our claim that the industrization was closely related with the power revolution.

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